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**AUTOMATED CARTRIDGE EXCHANGE SYSTEM AND METHOD
FOR HIGH-DENSITY AUTOMATED TAPE LIBRARIES**

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BACKGROUND OF THE INVENTION

1. Field of the Invention:

The present invention relates generally to high-density automated tape libraries, and in particular, but
10 not exclusively, to a cartridge positioning system for automated tape libraries. More specifically, the present invention provides an improved system and method for automatically exchanging cartridges between high-density automated tape libraries.

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2. Background of the Invention:

An automated tape library is a self-contained unit that includes a plurality of magnetic tape cartridge storage locations (e.g., cells, slots) that are serviced
20 by a robot mechanism. The robot mechanism retrieves a magnetic tape cartridge from its assigned magnetic tape cartridge storage location in the automated tape library, and loads the retrieved cartridge into a designated tape drive. The tape drive facilitates the reading and/or
25 writing of data from and/or to the magnetic media on the surface(s) of the tape. When the tape drive is finished with the magnetic tape cartridge, the robot mechanism retrieves the cartridge from the tape drive and returns the cartridge to its assigned storage location in the
30 automated tape library.

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Automated tape libraries are typically enclosed by a housing to prevent users from interfering with, or being injured by, the robot mechanism. Typically, a cartridge access port is provided to allow users to enter and retrieve magnetic tape cartridges into and from the automated tape library. The cartridge access port provides an apparatus to receive a magnetic tape cartridge from a user and then present the cartridge to the robot mechanism for storage in an assigned magnetic tape cartridge storage location. The apparatus can reverse this operation to enable the robot mechanism to retrieve the tape from the assigned storage location and present it at the access port to the user.

The existing enterprise class data storage market requires high-density, high performance, highly scalable, highly reliable, available and readily serviceable automated tape library systems. An example of such an enterprise class automated tape library system is the Streamline™ SL8500 Modular Library System produced by Storage Technology Corporation of Louisville, Colorado. Such modular library systems are composed of a plurality of juxtaposed automated tape cartridge libraries. A pass-through mechanism is provided to interconnect two juxtaposed automated tape cartridge libraries to enable a robot mechanism in one automated tape cartridge library to pass a selected tape cartridge to a robot mechanism in the second automated tape cartridge library without user intervention. This ability to automatically exchange magnetic tape cartridges between libraries provides a load balancing capability, whereby idle tape drives in an

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automated tape cartridge library are accessible by a robot mechanism located in an adjacent automated tape cartridge library via the pass-through mechanism.

However, in order to meet the stringent density,
5 performance, scalability, reliability, availability and serviceability requirements imposed by the enterprise class data storage market, the automated exchange of tape cartridges between automated tape libraries needs to be accomplished without significantly compromising the
10 cartridge density of one or both of the juxtaposed automated tape libraries involved. Also, any apparatus used for automated cartridge exchange needs to provide adequate redundancy to ensure that the stringent enterprise class data storage availability requirements
15 are met. Furthermore, such an automated cartridge exchange apparatus needs to meet the stringent enterprise class data storage serviceability requirements, by enabling the service of faulty components of the exchange apparatus without having to take any additional component
20 of one or both of the adjacent automated tape libraries off-line.

A significant problem with the existing automated tape cartridge exchange devices is that their components are not serviceable without taking one or both of the
25 linked automated tape libraries off-line. Another significant problem with many of the existing automated tape cartridge exchange devices is that only one magnetic tape cartridge can be exchanged at a time, and certain host software may be required to control the operations
30 of the exchange devices and the multiple automated tape

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libraries involved. In any event, these exchange devices do not provide adequate serviceability and redundancy to meet the enterprise class data storage requirements currently imposed. Other existing automated tape
5 libraries include a pass-through mechanism that provides some serviceability, but does not provide a redundant tape cartridge data path. However, the serviceability of these automated tape libraries is limited significantly, because the pass-through mechanism can be accessed for
10 service only from the top due to the close proximity of the libraries involved. Consequently, in order to service an existing pass-through mechanism, at least one of the adjacent tape libraries has to be shut down.

Notwithstanding the above-described limitations of
15 the existing automated tape library systems and cartridge exchange devices, a more critical problem relates to the inability of the existing automated tape library systems and cartridge exchange devices to meet the stringent density requirements imposed by the enterprise class data
20 storage market. In other words, since the existing cartridge exchange devices are interposed between adjacent tape libraries, the relatively large size and structure of these devices significantly affects the ability of designers to minimize the distance between the
25 tape libraries, which in turn, significantly limits the overall cartridge density of the automated tape library system involved.

Therefore, it is desirable to have an improved system and method for automatically exchanging tape
30 cartridges between automated tape libraries arranged in

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close proximity, which system and method provide redundancy, high serviceability, and increased cartridge density relative to the prior art approaches.

SUMMARY OF THE INVENTION

The present invention provides a system, method and program for automatically exchanging tape cartridges
5 between a plurality of automated tape libraries arranged in close proximity. In accordance with the present invention, the automated cartridge exchange system translates a forward and reverse stroke in a first axis directed parallel to the sidewalls of two adjacent tape
10 libraries to a radial movement directed to a second axis perpendicular to the first axis and into and out of the tape libraries (e.g., via a pass-through port in each library). Thus, the present invention maximizes the cartridge density of the overall library system by
15 limiting the width of the main assembly of the automated cartridge exchange system and thereby minimizing the distance between the two adjacent libraries. Also, in accordance with the present invention, the automated cartridge exchange system can be blind-mated to the
20 adjacent libraries and thus provide a hot-swappable (on-line), readily serviceable component that is not available from the existing approaches. Furthermore, a plurality of such automated cartridge exchange systems can be installed between adjacent automated tape
25 libraries to provide the redundancy not available from the existing approaches.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, however, as well as a preferred mode of use, further objectives and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

10 **Figures 1A and 1B** depict related diagrams illustrating an exemplary system of automated tape libraries in which the present invention may be implemented;

15 **Figure 2** depicts a diagram illustrating a portion of an automated tape library depicted in **Figures 1A and 1B**; and

20 **Figures 3A-3C** depict related diagrams illustrating an automated cartridge exchange system for automated tape libraries in accordance with a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

With reference now to the figures and in particular with reference to **Figures 1A and 1B**, related diagrams are depicted illustrating an exemplary system of automated tape libraries in which the present invention may be implemented. System **100** includes a plurality of automated tape libraries **102, 104**. For example, system **100** can be an SL8500 Modular Library System produced by Storage Technology Corporation, and each automated tape library **102, 104** can be an individual SL8500 automated tape library unit or module. Notably, although only two automated tape libraries **102, 104** are shown, the depicted example is not intended to impose an architectural limitation with respect to the present invention and may include more than two automated tape libraries. Also, the present invention is not intended to be limited to any particular type or implementation of automated tape library system.

Essentially, an important function of the present invention is to enable the exchange of cartridges between automated tape libraries located in close proximity and/or juxtaposed with respect to one another. In a preferred embodiment, a cartridge exchange unit is provided for exchanging cartridges between two automated tape libraries located in close proximity to each other. For this embodiment, the cartridge exchanges unit is motor driven and self-calibrating so as to ensure a robust design. The linkage of the cartridge exchange unit translates a forward and reverse stroke in a first axis directed

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parallel to the sidewalls of two adjacent tape libraries
to a radial movement directed to a second axis
perpendicular to the first axis and into and out of the
tape libraries (e.g., via a pass-through port in each
5 library). This linkage and the structure of the cartridge
exchange unit minimize the distance between the two
juxtaposed libraries and thus maximizes cartridge density
for the automated tape library system. Also, the
cartridge exchange unit can be blind-mated to the adjacent
10 libraries and thus provide a hot-swappable (on-line),
readily serviceable component that is not available in the
prior art. Furthermore, a plurality of such cartridge
exchange units can be installed between two juxtaposed
automated tape libraries to provide the redundancy not
15 available in the prior art.

Specifically, referring again to **Figure 1A**, a top-
down view of automated tape library **102** is depicted that
includes base storage frame assembly **106** and tape
drive/electronics frame assembly **112**. Similarly, for this
20 illustrative example, a top-down view of automated tape
library **104** is also depicted that includes base storage
frame assembly **108** and tape drive/electronics frame
assembly **110**. System **100** also includes cartridge exchange
unit **114** arranged between automated tape library **102** and
25 automated tape library **104**. For this embodiment,
cartridge exchange unit **114** includes two components: sub-
frame **118** and end cam **116a**. As described in detail below,
the switching and positioning mechanisms of cartridge
exchange unit **114** are arranged primarily on sub-frame **118**.
30 As such, end cam **116a** is structured so that a first

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section of end cam **116a** enters a pass-through port of automated tape library **102**, and a second section of end cam **116a** enters a pass-through port of automated tape library **104**. Consequently, a robot mechanism (not shown) of automated tape library **102** can access the first section of end cam **116a**, and a robot mechanism (not shown) of automated tape library **104** can access the second section of end cam **116a**. The robot mechanism of automated tape library **102** can also access cartridge array **109a** for retrieval and storage of individual tape cartridges. Although only cartridge array **109a** is shown in automated tape library **102**, it should be understood that this cartridge array is shown in **Figure 1A** for illustrative purposes only, and automated tape library **104** can also include at least one such cartridge array.

Referring now to **Figure 1B**, a perspective view of automated tape library system **100** is depicted. As can be seen, for this embodiment, automated tape library **102** includes a plurality of cartridge arrays **109a-109d**. Again, although only cartridge arrays **109a-109d** are shown in automated tape library **102**, it should be understood that these cartridge arrays are shown in **Figure 1B** for illustrative purposes only, and automated tape library **104** can also include a similar plurality of cartridge arrays. For example, if automated tape library system **100** is to be implemented as an SL8500 Modular Tape Library, then automated tape libraries **102**, **104** can be implemented as substantially identical automated tape library units or modules. Automated tape library **102** also includes a plurality of pass-through ports **116a-116d**. Although not

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shown in the perspective view of **Figure 1B**, automated tape library **104** can also include a plurality of pass-through ports arranged adjacent to pass-through ports **116a-116d**.

Those of ordinary skill in the art will appreciate
5 that the hardware depicted in **Figures 1A** and **1B** may vary. For example, automated tape library **102** may be structured differently (e.g., internally or externally) from automated tape library **104**. In any event, automated tape libraries **102**, **104** should be structurally and/or
10 functionally compatible with each other to the extent that cartridge exchange unit **114** can transport and exchange cartridges between automated tape library **102** and automated tape library **104** (e.g., via one or more pass-through ports **116a-116d** of automated tape library **102** and
15 one or more counterpart pass-through ports of automated tape library **104**).

Referring now to **Figure 2**, for illustrative purposes, expanded view **200** of array **109a** and pass-through port **116a** of automated tape library **102** of **Figures 1A** and **1B** is
20 depicted in accordance with a preferred embodiment of the present invention. Notably, expanded view **200** of array **109a** and pass-through port **116a** also illustrates the structure and arrangement of each of arrays **109b-109d** and pass-through ports **116b-116d**. Similarly, expanded view
25 **200** can also be used to illustrate one or more arrays and pass-through ports of automated tape library **104**. In this case, the pass-through ports for automated tape library **104** are located adjacent to the pass-through ports of automated tape library **102**, and therefore, can be
30 illustrated by a reverse (mirror) image of view **200**.

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Expanded view **200** shows pass-through port **202** (e.g., any one of pass-through ports **116a-116d** depicted in **Figure 1B**). For example, pass-through port **202** may be a rectangular cut-away portion of a sidewall of automated tape library **102**. Referring also to **Figures 1A** and **1B**, note that end cam **116a** of cartridge exchange unit **114** protrudes or "passes through" respective sidewalls of automated tape libraries **102**, **104**. Similarly, for this embodiment, end cams for additional cartridge exchange units (not shown) may be envisioned protruding through pass-through ports **116b-116d** of automated tape library **102** and adjacent counterpart pass-through ports (not shown) of automated tape library **104**. Cartridge magazine **203** is positioned in and preferably protrudes through pass-through port **202**. As described in detail below, cartridge magazine **203** is movably attached to an end cam (e.g., end cam **116a**) of a cartridge exchange unit (e.g., cartridge exchange unit **114**). As such, cartridge magazine **203** includes a plurality of slots **210**, **212**, **214**. For this exemplary embodiment, slot **210** can be an inactive slot (e.g., may or may not be used for cartridge storage), and slots **212**, **214** can be active slots that are used for cartridge storage. Thus, a robot mechanism (not shown) of automated tape library **102** can access slots **210**, **212** and **214** for retrieval and storage of cartridges.

Array section **204** (e.g., component of array **109a**) is located adjacent and below pass-through port **202** and cartridge magazine **203** (e.g., whenever cartridge exchange unit **114** positions cartridge magazine **203** in pass-through port **202**). For example, in an SL8500 library environment,

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array section **204** is an abbreviated section (e.g., to allow for cartridge magazine **203**) that can include eight cells (or slots) for cartridge storage. Also, cartridge array sections **206**, **208** are located adjacent and to each side of cartridge magazine **203** and array section **204**. As such, any of the active cells or slots of cartridge magazine **203** and array sections **204**, **206**, **208** can be accessed for retrieval and storage by a robot mechanism (not shown) of automated tape library **102**. Those of ordinary skill in the art should appreciate that expanded view **200** illustrates that a similar arrangement of a cartridge magazine and adjacent array sections is also available for use in conjunction with a robot mechanism of automated tape library **104**.

Referring now to **Figures 3A-3C**, related diagrams illustrating different views of an automated cartridge exchange system for automated tape libraries are depicted in accordance with a preferred embodiment of the present invention. For example, the automated cartridge exchange system described herein can be used to implement the cartridge transport, exchange and storage functions of cartridge exchange unit **114** in **Figures 1A-1C**.

Essentially, **Figure 3A** depicts a perspective view of automated cartridge exchange system **300**, **Figure 3B** depicts a top-view of automated cartridge exchange system **300**, and **Figure 3C** depicts a second view of automated cartridge exchange system **300** with the same perspective as **Figure 3A**. However, **Figure 3A** differs from **Figure 3C** primarily in that automated cartridge exchange system **300** in **Figure 3A** (and **3B**) is depicted with cartridge magazine **304**

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positioned at the right-most portion of end cam 302, and automated cartridge exchange system 300 in **Figure 3C** is depicted with cartridge magazine 304 positioned at the left-most portion of end cam 302. Thus, in accordance
5 with the present invention, these differences illustrate the cartridge exchange features of automated cartridge exchange system 300.

Specifically, referring to related **Figures 3A-3C**, certain salient components of automated cartridge exchange
10 system 300 include end cam 302, magazine 304, switch motor 306, drive motor 308, and controller card 310. End cam 302 is fixedly attached to (e.g., bolted together with) main guide assembly 338. For this exemplary embodiment, end cam 302 and main guide assembly 338 both form a fixed
15 framework or base structure for automated cartridge exchange system 300. As such, switch motor 306, drive motor 308 and controller card 310 are mounted on main guide assembly 338. Additional salient components of automated cartridge exchange system 300 include left track
20 312 and right track 314. As illustrated more clearly in **Figure 3B**, left track 312 and right track 314 are cutaway portions of end cam 302 and main guide assembly 338 that form individual "tracks" which separately extend from main guide assembly 338 to the left-most and right-most
25 portions, respectively, of end cam 302. Magazine carriage 316 is movable and can be positioned at any location on left track 312 or right track 314.

Figures 3A and **3B** depict magazine carriage 316 positioned on right track 314 at the right-most portion of
30 end cam 302, and **Figure 3C** depicts magazine carriage 316

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positioned on left track **312** at the left-most portion of end cam **302**. Preferably, magazine carriage **316** includes a set of rollers or wheels to enhance movement of magazine carriage **316** along left track **312** or right track **314**.

5 Magazine **304** is coupled to magazine carriage **316** (e.g., via one or more bolts) through left track **312** or right track **314** so that magazine **304** and magazine carriage **316** can be positioned in unison anywhere along left track **312** or right track **314**.

10 Automated cartridge exchange system **300** also includes a plurality of mounting blocks **318a-318d** for attaching end cam **302** to a respective sidewall of each automated tape library involved (e.g., libraries **102**, **104**). For example, considering the relative orientations of end cam **116a** in
15 **Figures 1A-1B**, and end cam **302** in **Figures 3A-3C**, mounting blocks **318b** and **318d** can be used to attach end cam **302** to a sidewall of automated tape library **102**, and mounting blocks **318a** and **318c** can be used to attach end cam **302** to a sidewall of automated tape library **104**.

20 Focusing on **Figure 3B**, switch belt **342** couples the bi-directional rotational force of switch motor **306** to switch linkage **320**. Thus, for example, a rotational force of switch motor **306** in a clockwise direction is transferred via switch belt **342** to cause switch linkage
25 **320** to move in a clockwise direction. Similarly, for example, a rotational force of switch motor **306** in a counter-clockwise direction is transferred via switch belt **342** to cause switch linkage **320** to move in a counter-clockwise direction. For this embodiment, switch linkage
30 **320** is attached to switch levers **322a** and **322b**. One link

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of switch linkage 320 is attached to switch lever 322a, and a second link of switch linkage 320 is attached to switch lever 322b. Therefore, switch linkage 320 translates a clockwise rotation of switch motor 306 to a clockwise rotation of switch levers 322a and 322b. Similarly, switch linkage 320 translates a counter-clockwise rotation of switch motor 306 to a counter-clockwise rotation of switch levers 322a and 322b. Thus, a clockwise rotation of switch motor 306 can position switch lever 322a so as to "close" left track 312 and "open" right track 314 for movement of magazine carriage 316 and magazine 304. This feature is illustrated in **Figure 3B**. Conversely, a counter-clockwise rotation of switch motor 306 positions switch lever 322a so as to "open" left track 312 and "close" right track 314 for movement of magazine carriage 316 and magazine 304. This feature is illustrated in **Figure 3C**. For this exemplary embodiment, the rotational direction of switch motor 306 controls the destination (e.g., pass-through port of automated tape library 102 or 104) of magazine 304 and any cartridge(s) stored therein. Switch brackets 324a and 324b can be used for attaching respective switch levers 322a and 322b to main guide assembly 338.

Additionally, automated cartridge exchange system 300 includes a plurality of drive components for positioning magazine carriage 316 and magazine 304. For this embodiment, top end plate 326 and bottom end plate 332 are attached (e.g., bolted) to main guide assembly 338. A plurality of linear rails 330 are attached at opposite ends to top end plate 326 and bottom end plate 332 so as

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to span the distance between top end plate 326 and bottom end plate 332 with clearance to main guide assembly 338. Drive carriage 328 includes a plurality of guide channels 329a and 329b arranged parallel to linear rails 330. The plurality of linear rails 330 can be inserted through
5 respective guide channels 329a and 329b so that drive carriage 328 can be slid and positioned anywhere along linear rails 330. Drive belt 336 is coupled between drive motor 308 and idler pulley 340 and also attached to a
10 sidewall of drive carriage 328. Therefore, drive belt 336 can translate a rotational force from drive motor 308 to a linear force at drive carriage 328 in order to position drive carriage 328 in a linear direction along linear rails 330. For this exemplary embodiment, a clockwise
15 rotation of drive motor 308 causes drive carriage 328 to move in a line towards end cam 302. Conversely, a counter-clockwise rotation of drive motor 308 causes drive carriage 328 to move in a linear direction away from end cam 302. Blind mate opening 334 is provided in controller
20 card 310 to enhance the ability to hot-swap components and thereby increase reliability. Link arm 344 is attached at one end to drive carriage 328 and at the opposite end to magazine carriage 316 so as to synchronize the movement of magazine carriage 316 with that of drive carriage 328
25 (e.g., drive carriage 328 drives magazine carriage 316).

In an exemplary operation, a controller subsystem of an automated tape library (e.g., library 102 or 104 in **Figures 1A-1B**) initiates a pass-through operation to exchange one or more cartridges from one tape library to
30 an adjacent tape library. Assuming, for illustrative

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purposes, that magazine 304 (**Figures 3A-3C**) is initially positioned in a pass-through port of library 104, and a robotic "hand" of library 104 places a data cartridge into a slot (e.g., active slot 212 in **Figure 2**) of magazine 304. Controller card 310 sends an appropriate drive signal to drive motor 308 that causes drive motor 308 to rotate in either a clockwise or counter-clockwise direction. In response, drive motor 308 rotates in a selected direction and thereby moves drive belt 336 accordingly. In turn, drive belt 336 "pulls" or "pushes" drive carriage 328 along linear rails 330 (e.g., toward or away from bottom end plate 332 dependent upon the rotational direction of drive motor 308). Link arm 344 transfers the movement of drive carriage 328 to magazine carriage 316.

For this example, in order to transport one or more cartridges from automated tape library 104 to automated tape library 102, controller card 310 causes drive motor 308 to rotate counter-clockwise so as to "pull" magazine carriage 316 along right track 314 and away from the pass-through port of library 104 until magazine carriage 316 reaches a "neutral" position (e.g., a location below the point of convergence of left track 312 and right track 314 in **Figure 3B**). Placing magazine carriage 316 in this "neutral" position allows unimpeded movement of switch levers 322a and 322b. Controller card 310 sends an appropriate drive signal to switch motor 306, which causes (for this example) switch motor 306 to rotate in a counter-clockwise direction. Switch belt 342 transfers the rotational force from switch motor 306 to switch lever

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322b. For this example, this particular switching operation "closes" right track 314 and "opens" left track 312 for travel by magazine carrier 316. Clearly, an opposite switching operation would "open" right track 314 for travel by magazine carriage 316, and "close" left track 312. Controller card 310 then sends an appropriate drive signal to drive motor 308 to cause drive motor 308 to rotate (for this example) in a clockwise direction. This rotational force is transferred by drive belt 338 to drive carriage 328, which "pushes" drive carriage 328 forward and along linear rails 330 away from bottom end plate 332. Link arm 344 rotates in a counter-clockwise direction and transfers the movement of drive carriage 328 to magazine carriage 316. Magazine carriage 316 is driven along left track 312 and thereby moves magazine 304 to the pass-through port (e.g., pass-through port 202 in **Figure 2**) of automated tape library 102. A robotic "hand" of library 102 can retrieve the one or more cartridges stored in magazine 304.

Advantageously, in accordance with the present invention, the above-described linkage of the automated cartridge exchange system translates a forward and reverse stroke in a first axis directed parallel to the sidewalls of two adjacent tape libraries to a radial movement directed to a second axis perpendicular to the first axis and directed into and out of the tape libraries (e.g., via a pass-through port in each library). Thus, the present invention maximizes the cartridge density of the overall library system by limiting the width of the main assembly of the automated

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cartridge exchange system and thereby minimizing the distance between the two adjacent libraries. Also, in accordance with the present invention, the automated cartridge exchange system can be blind-mated to the adjacent libraries and thus provide a hot-swappable (on-line), readily serviceable component that is not available from the existing approaches. Furthermore, a plurality of such automated cartridge exchange systems can be installed between adjacent automated tape libraries to provide the redundancy not available from the existing approaches.

It is important to note that while the present invention has been described in the context of a fully functioning automated cartridge exchange system including data processing functions, those of ordinary skill in the art will appreciate that the processes of the present invention are capable of being distributed in the form of a computer readable medium of instructions and a variety of forms and that the present invention applies equally regardless of the particular type of signal bearing media actually used to carry out the distribution. Examples of computer readable media include recordable-type media such a floppy disc, a hard disk drive, a RAM, CD-ROMs, and transmission-type media such as digital and analog communications links.

The description of the present invention has been presented for purposes of illustration and description, and is not intended to be exhaustive or limited to the invention in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in

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the art. The embodiment was chosen and described in order to best explain the principles of the invention, the practical application, and to enable others of ordinary skill in the art to understand the invention for
5 various embodiments with various modifications as are suited to the particular use contemplated.